1-1-2002

Effects of long-term, low moisture storage on specialty corn relative to conventional corn

Segokgo Nelson Kabomo
Iowa State University

Effects of long-term, low moisture storage on specialty corn relative to conventional corn

by

Segokgo Nelson Kabomo

A thesis submitted to the Graduate College

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agricultural Engineering (Food and Process Engineering)

Program of Study Committee:
Carl J Bern, Major Professor
Theodore B Bailey
Thomas J Brumm
Graeme R. Quick

Iowa State University

Ames, Iowa

2002

Graduate College

Iowa State University

This is to certify that the master's thesis of

Segokgo Nelson Kabomo

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

Dedicated to my wife, Bontle, and our children in appreciation of their love and care.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GENERAL INTRODUCTION

The diversity of climatic conditions under which corn (*Zea mays*) is able to grow and develop makes it a world crop (Hallauer, 1994). Corn (maize) is found in tropical as well as temperate climate zones and is considered one of the major cereal grains grown in the world, exceeded only by rice and wheat (FAO, 1992).

Grain production is seasonal because of the seasonality of the agronomic conditions that are conducive for plant growth and crop development to attain maximum yields. On the other hand, consumption and processing continue throughout the year. It is, therefore, important to maintain 'quality' of produce until the time of consumption and / or processing. However, previous studies have shown that grain quality declines with time after harvest (Steele et al, 1969 and Potter, 1968). In addition, the rate and level of deterioration is influenced by temperature of storage, grain moisture content and storage time (Green, 1961, Steele, 1967) due to deterioration of a grain-mass from respiration of the grains and micro-organisms. Insects can also be significant causes of deterioration. Insect damage is not considered in this study.

In tropical climate zones ambient temperatures are very high most of the year. In Botswana the winter minimum temperature is 5 °C and summer maximum is 35 °C. This leads to substantial loss of quality during storage. In addition, since corn is one of the staple foods in Botswana this study would provide valuable storage information for the author.

Storage conditions

Green (1961) and Potter (1968) studied the rate and extent of storage spoilage of corn on short-term basis and found a direct relation between temperature and the rate of deterioration. Fawole (1969) observed a reduction in the presence of mold on corn stored below 2 ° C over 74 days in storage at all the different levels of moisture used in the study.

The presence and activity of micro- organisms accelerates grain spoilage, and fungi are by far the most important of all microbes that cause storage damage (Green 1961). Studies have shown that the survival of storage fungi is optimum at relative humidity between 62 % and 90 % (Ross et al, 1973 and Green, 1961).

Studies have shown a progressive deterioration of stored grains over time (Potter, 1968). Respiration of micro- organisms is not instantaneous and, therefore, becomes more evident over time. A number of short- term storage studies have been done to quantify grain deterioration over time in storage (Steele 1967, Fawole 1969, Potter 1968, Ileleji 2002). The rate and level of deterioration have not been documented over periods exceeding a few months. In this study the longest stored grain was kept for 18 months.

Corn hybrids

Most storage information available to date was attained on commodity (conventional) corn. However, in the past few years there has been a substantial increase in planting of new types of corn hybrids by farmers in the USA (USA grain council 2000 / 2001). These value-enhanced (specialty) corn hybrids contain more oil, protein, or starch, or have improved processing characteristics compared to the conventional (commodity) corn hybrids. Some examples of these value-enhanced corn hybrids include high amylose (Ha), high oil (Ho), food Grade (Fg), and waxy (Wx) corn hybrids. Information on storage characteristics of these specialty corn hybrids is lacking.

Explanation of Thesis format

This thesis consists of one paper written in the format required for publication by the Journal of Applied Engineering in Agriculture. Because of the publication guidelines, tables and figures have been placed at the end of the paper. A general conclusion follows the paper. References cited in the general introduction follow the general conclusion.

The thesis includes appendices A, B, C, D, E and F. Appendix A gives example calculation for formulation of glycerol / water solutions used to control corn moisture during storage. Appendices B, C, D, E, and F give raw data for dry matter loss (DML), damaged kernel total (pooled samples), fat acidity value (FAV), differential scanning calorimetry (DSC), and near infrared transmittance (NIR) for the 18 months storage, respectively. Appendices will not be included in the manuscript for publication to the Journal of Applied Engineering in Agriculture.

EFFECTS OF LONG-TERM, LOW MOISTURE STORAGE ON SPECIALTY CORN HYBRIDS RELATIVE TO COMMODITY CORN

(A paper to be submitted to the Journal of Applied Engineering in Agriculture)

Segokgo Nelson Kabomo, Carl J Bern, Jenni L. Briggs, Theodore B Bailey

ABSTRACT

Kernel temperature and moisture content influence the storability of corn (*Zea mays*). Previous studies showed variability in quality deterioration of commodity corn under different storage temperature and moisture contents. However, in recent years specialty corn varieties are being grown in the USA and it has become necessary to investigate the storability of these specialty corn hybrids relative to the commodity (conventional) corn varieties.

Four specialty corn hybrids, one commodity corn and an oil treated commodity corn were stored at 2 temperature levels (10 and 27 °C) and 2 moisture levels (12 and 15 %, wet basis) over 18 months to compare their quality over time.

At the 10 °C temperature, there was no difference in the rates of quality deterioration between moisture levels, but the hybrids were different.

At the 27 °C temperature, the high oil (Ho) corn deteriorated faster than all the others followed by the high amylose (Ha), and food grade (Fg) corn. The waxy (Wx) corn deteriorated slower than the control. At this temperature, the 15 % moisture corn deteriorated faster than the 12 % moisture corn on all hybrids.

In addition, the rate of deterioration was lower on the oil treated corn than the control, indicating preservative effects of adding 400 ppm light mineral oil on corn.

INTRODUCTION

Production of grains is seasonal while consumption and / or processing continue through the year, hence the need to store grains until the time of use. Potter (1968) stated that, from the moment food is harvested, it undergoes progressive deterioration over time and the rate of (quality) deterioration is temperature and moisture dependent.

Evolution of CO_2 has been used as an index to quantify the rate of corn deterioration based on the general respiration reaction as may be demonstrated by oxidation of glucose according to the model:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6CO_2 + 6H_2O + 2834\ kJ \qquad (1)$$

Equation 1 above was adopted to represent a simplified grain respiration process and from this equation it can be calculated that 14.7 g of CO_2 gas is released from 1 kg of the original dry matter when 1.0 % of the grain-dry matter (glucose) is consumed. According to Saul and Steele (1966), when 7.35 g of CO_2 per kg or 0.5 % of the original dry matter is lost to deterioration, there is, on average, a loss of one commercial United States grade because of damaged kernels. The loss of quality measured using this index has been documented over the years at various combinations of temperature and moisture for commodity corn (Bern et al, 2002).

Factors that influence grain deterioration during storage include: temperature (Fawole, 1969 and Green 1961), moisture content (Potter, 1968), storage time (Fawole, 1969 and Steele et al, 1969), hybrid (Ileleji, 2002) and preservatives added (Dugba, 1994).

Temperature

'Low' temperature of storage has been used as a means to preserve quality of produce, for example 'cold' temperature refrigeration. At very low temperature, the activity of microorganisms is retarded, or sometimes stopped completely at extreme low temperatures, leading to reduced microbial damage. As temperature increases, the microbes become more active and cause damage to stored grains. Steele et al (1969) formulated models that determine the 'allowable storage time' (AST), the time during which corn is expected to lose dry matter equivalent to 0.5 % of the original dry matter. When temperature of storage is increased, the time to 0.5 % dry matter loss decrease rapidly. Bern et al (2002) includes a number of equations for predicting the DML using CO_2 evolution as an index.

Moisture

Work by Steele et al (1969) showed different rates of deterioration at different moisture levels. This was also incorporated into the determination of the AST and showed a sharp increase in the rate of deterioration with increase in moisture, leading to shorter AST's. In this paper, 'storability' refers to the rate of deterioration caused by fungi growing on corn kernels. This rate of fungi growth is, on the other hand, is indicated by the change in the levels of parameters measured at the different sampling times.

Storage time

Studies have shown a progressive deterioration of stored grains over time (Potter, 1968). Growth of micro- organisms is not instantaneous and, therefore, becomes more evident over time. A number of short- term storage studies have been done to quantify grain deterioration (Steele, 1967, Fawole, 1969 and Potter, 1968). Time to 0.5 % DML has been used extensively as an index to estimate AST at reference conditions.

The rate and level of deterioration have not been documented over periods exceeding the AST. Longer- term studies are needed because grain managers sometimes need to store corn for over one year.

Properties of corn- starch

Studies have revealed differences in thermal properties of starch between crops, for example between corn, wheat, or potato. Some of these properties include the process of gelatinization. Starch gelatinization is a process that occurs when starch granules are heated in the presence of water, resulting in the disruption of molecular order within the granules. This process is endothermic and occurs over a temperature range unique for a given type of starch. Gelatinization occurs because bonds between the starch molecules in the granules are broken by thermal energy. Starches from corn types of different botanical origin also have different gelatinization properties. For example, gelatinization for normal corn occurs at 60.2 – 71.0 $^{\circ}$ C, while for waxy corn it occurs at 64.5 – 71.0 $^{\circ}$ C (Chen, 1997, Yamin, 1997). The most common method to analyze thermal properties of starch is the differential scanning calorimetry (DSC). The DSC was used in this study to monitor the properties of starch at different sampling times.

Properties of corn oil

Fatty acids are present in small quantities in corn under certain conditions of storage, but may increase due to enzymatic hydrolysis of fats and proteins (Ileleji, 2002). Grains rich in lipids are vulnerable to enzymatic hydrolysis and fatty acids are sensitive products of oxidation. Over time in storage the free fatty acids (FFA) tend to increase (Ileleji, 2002). The presence of FFA, on the other hand, is undesirable for processing purposes as it necessitates additional costs to remove them (Rukunudin, 1998). The AACC method was used to measure the amounts of FFA at different sampling times.

Preservative effects of oil

Application of preservatives may be used to slow down deterioration of stored produce, but would not altogether eliminate grain deterioration. A number of such additives exist including mineral oil on shelled corn. Al- Yahya (1993) found that addition of mineral oil to shelled corn extended the corn AST of high moisture corn. It is necessary to investigate the preservative effects of mineral oil on low moisture corn stored for longer than one year.

Corn hybrids

In recent years production of specialty corn has been increasing (USA Grains Council, 2000 / 2002). Specialty hybrids are bred for specific traits required for end use, such as milling ability, oil content, etc. The compositional differences may be important to maintenance of grain quality. Ileleji et al (2002) found that high oil corn hybrids (about 6 % oil, wet basis) deteriorated faster than hybrids with normal oil content (3 to 4 % oil, wet basis) on a short- term, high moisture study. This being a specialty corn type, the findings further suggest differences in storability between commodity and specialty corn types. In order to quantify the storability of specialty corn hybrids, a study is needed comparing storage characteristics of specialty and commodity corn hybrids.

OBJECTIVES

The objectives of this study were:

1) To compare the storability of four specialty corn hybrids and one commodity corn hybrid at 2 temperatures (10 and 27 ^{o} C), and at 2 moisture levels (12 and 15 %) over 18 months storage.

2) To investigate the preservative effects of 400 parts per million (ppm, weight by wet weight basis) of light mineral oil on shelled corn stored at 2 temperatures (10 and 27 ^{o} C), and at 2 moisture levels (12 and 15 %) over 18 months storage.

MATERIALS AND METHODS

During the period between December 2000 and June 2002, a storage experiment was carried out to investigate the effects of long- term, low moisture storage on four specialty corn hybrids in comparison to a commodity corn and an oil treated commodity corn. The experiment was conducted in the Biomaterials Laboratory in Davidson Hall at Iowa State University, Ames, Iowa. Corn samples weighing about 2 kg were stored at two temperature levels (10 and 27 ^{o} C) and at two moisture levels (12 and 15 %)* for a period of 18 months. The experiment was started on December 5th, 2000 and was terminated on June 6th, 2002.

Experimental corn

All the corn hybrids used in this study were combine-harvested during the fall of 2000 at moisture levels between 13 % and 16 % and stored at about 5 ^{o} C until the experiment was set up and started on December 5th 2000. Broken corn and foreign material (BCFM) were removed from all samples by screening over a 4.76 mm (12/64 inch) round-holed screen using a Carter- Day Dockage tester (CEA Carter-Day Co., Minneapolis, MN). Non-corn materials larger than the screen openings were removed manually.

i. Commodity corn (Control, C)

The commodity corn hybrid was Asgrow RX 686 RRYG. This corn is known for its excellent emergence with very good seedling growth. It also features good ear flex and very good stalk strength. With its combination of Yieldgard ® corn borer and Roundup Ready ® traits, this product has a season- long corn borer protection and cost-effective weed control (Farm Source / Asgrow, 2002). The corn was harvested during September of 2000 at the Agronomy and Agricultural Engineering Research Center (AERC) 15 km west of Ames, Iowa and delivered at 13.8 % moisture.

---

* All moistures are % wet basis.

ii. Control + 400 ppm light mineral oil (C+ O)

One portion of the Asgrow RX 686 RRYG corn was treated with 400 parts per million (ppm, weight by wet weight basis) of 23436 Drakeol GD-LP light mineral oil and included in this study to investigate the preservative effects of the oil on corn during storage.

iii. High Amylose corn (Ha)

The high amylose corn was Wilson Seeds number 1785, harvested during September 2000 and delivered at 15.1 % moisture. The term 'amylose' describes the straight- and branched-chain components of starch (Hallauer, 1994). Normal amylose contents of corn range below 35 % amylose starch while high amylose hybrids have 50 % amylose starch or more. The high amylose yellow corn varieties also have high protein content. (Wilson Seeds, 2002)

iv. High oil corn (Ho)

The high oil corn was Pioneer number 34B25, harvested in September 2000 and delivered at 13.3 % moisture. Normal oil content of corn usually ranges between 3 and 4 percent, and high oil corn has between 6 and 8 % oil (dry basis) (Hallauer, 1994). The high oil corn variety was included for comparison with the commodity corn.

v. Food grade corn (Fg)

The (white) food grade corn was Wilson Seeds number 1851 W, harvested in September 2000 and delivered at 13.7 % moisture. This hybrid typically has large kernels and is approved for food and feed in the USA and Japan (Wilson Seeds, 2002).

vi. Waxy corn (Wx)

The waxy corn hybrid was Dekalb number 6295, harvested in September 2000 and delivered at 13.9 % moisture. Waxy corn is defined as corn with 100 % amylopectin in its starch. A majority of waxy grain are grown under contract to wet milling companies. As early as the 1940's waxy corn has been used in livestock feed due to its apparent potential to increase feed conversion efficiencies (Halluaer, 1994). This hybrid was also included in the experiment to compare its storability to that of the commodity corn.

Experimental design

The experiment was a split-plot design. Two temperature regimes (10 and 27 ^{o} C) were used in the experiment, with 2 moisture levels (12 and 15 %). The six hybrids represented sub-plots within temperature and moisture. Each of the 24 treatment combinations (i.e. 2 temperatures x 2 moistures x 6 hybrids) was replicated 3 times, thereby resulting in 72 samples in storage. Samples were taken at time 0, 6, 12 and 18 months. Quality differences were analyzed at the sampling times.

Storage conditions

Three temperature-controlled storage chambers were used to effect replications at each of the two temperature levels (10 and 27 ^{o} C), resulting in six storage chambers for the experiment. Inside each of the six chambers there were 3 containers with glycerol/water solutions at 58 % relative humidity (RH) used for storage of the 12 % corn samples and 3 other containers with 78 % RH solutions used for storage of the 15 % corn. Two samples, each from a different hybrid, were stored above each glycerol solution.

Moisture control

The corn samples were suspended above solutions (baths) of glycerol and water. Solutions were prepared with 26 % water and 74 % glycerol (by volume) to create a 58 % RH for storage of the 12 % moisture corn samples (Calculations in Appendix A). Another set of solutions were prepared with 43 % water and 57 % glycerol to create 76 % RH for storage of the 15 % moisture samples (Braun & Braun, 1958, Winston and Bates, 1960). The % RH of solutions used for corn storage were based on the basis of equilibrium moisture content for yellow dent corn (ASAE standards, 1997). These were respectively 58 % RH for storage of 12 % corn and 76 % RH for storage of 15 % corn. Glycerol / water solutions were prepared at the same time, using the same glassware to ensure consistency of the solutions.

Moisture adjustment

Corn samples of each hybrid were split into two equal portions using the Boerner divider (Seedburo Equipment Co, Chicago, IL). One portion of the corn was dried down from the harvest moisture to 12 % by natural air-drying using the laboratory size dryers. The other portion was wetted to 15 % moisture level using a pre-determined volume of distilled water from a spray bottle, followed by thorough mixing to distribute the water evenly through the corn. Corn at the two moisture levels was left over night to attain equilibrium before being cut into smaller samples for storage at different conditions of temperature and moisture.

At the end of every month, moisture was measured on all samples using the GAC 2000 (Grain Analysis Computer, Dickey John Corporation, Auburn, IL). When the moisture levels were below the set points, those samples were suspended above a 100 % water bath to allow them to gradually re-gain their moisture up to the required level.

Sampling

At the start of the experiment, samples were taken out for analysis to determine the initial (t = 0 months) quality parameters for all hybrids on December 5, 2000. On June 6, 2001 (i.e. at t = 6 months) all the samples in store were repeatedly split using the Boerner divider (Seedburo Equipment Co, Chicago, IL) to take out one third of the original mass for quality analysis and the remaining corn was left on for continued storage. On December 6, 2001 the samples were then split into two equal halves for the third ($t = 12$ months) quality analysis. Finally, on June 6, 2002 the remaining samples were removed for the fourth and last ($t = 18$ months) quality analysis and the experiment was terminated. Since some of the quality tests required a considerable length of time to complete, the sub-samples were kept at 5 $^{\circ}$C between the time when they were sampled out of storage and the time of analysis.

Onset of experiment

Corn from each hybrid was split up into 12 equal portions of about 2 kg each. These samples were all placed into bottom perforated plastic containers. Samples were randomly allocated to four treatment combinations in three replications.

Insect problem

During the first month of storage insect pests (Indian red moth) were observed on all samples from the Ha corn stored at 27 $^{\circ}$C. Affected samples were placed in –18 $^{\circ}$C (0 $^{\circ}$F) for 48 hours after which they were placed back into 27 $^{\circ}$C for the next 48 hours. The samples were again placed in –18 $^{\circ}$C for another 48 hours after which they were returned to 27 $^{\circ}$C. This was meant to eliminate the pests, and / or their eggs, without application of chemicals; which might also kill fungi. This procedure effectively eliminated the pests for the rest of the storage duration.

Measurements of corn quality

i. Grain dry matter loss (% DML) was determined by material balance

During respiration of microbes, grain starch is used thereby resulting in a reduction of grain dry mass. The change in mass of stored samples over 6 months of storage time was calculated and recorded as % DML. Samples were measured using a Denver Instrument DI –

4K (Denver Instrument Company, Denver, CO) capable of weighing up to 4000 g with an accuracy of 0.01 g. A mass balance was used to determine DML at six-month intervals, and cumulative DML were determined over subsequent storage time to a maximum of 18 months.

ii. Damaged kernel total (DKT)

Samples weighing about 600 g, amounting to about ⅓ of each sample, were drawn every 6 months and analyzed for DKT by a licensed grain inspection agency (Central Iowa Grain Inspection Service, Inc., Des Moines, Iowa).

iii. Fat acidity value (FAV)

Fat acidity value (FAV) was determined by the rapid method for corn, AACC Method 02 – 03 A (AACC, 1999). The method involves extracting free fatty acids from milled samples of grain using purified grade toluene and titrating the extract with CO_2 –free standard solution of 0.0178 N Potassium Hydroxide (KOH). Titrations were done in three replications. Fat acidity values for each sample were averaged and reported as mg of KOH required to neutralize free fatty acids from 100 g of grain on a dry matter basis by using the formula given under AACC Method 02 – 01 A.

iv. Differential scanning calorimetry (DSC)

Samples (taken every six months) were analyzed for thermal properties with a DSC Exstar 6000 analyzer (Seiko Instruments, Inc.) equipped with a thermal analysis data station. About 100 g of corn were milled into fine flour and homogenized. A sample of between 8 and 10 mg of the flour was then weighed into aluminum pans and a pre-determined volume of distilled water was added to the sample to wet it to 66 % moisture. For each run, the sample was prepared, weighed and wetted, then sealed and allowed to stabilize overnight.

The DSC analyzer was calibrated and an empty pan was used as reference. Samples were heated at a rate of 10 ° C / minute from 30 to 110 ° C, and cooled down at 20 ° C / minute from 110 to 30 ° C (Yamin, 1997). Onset temperature (T_o, ° C), peak temperature (T_p, ° C), completion temperature (T_c, ° C) and enthalpy (ΔH, mJ/mg) of gelatinization were calculated automatically, on a sample dry weight basis. Because the peaks were symmetrical, the gelatinization range (R, ° C) was calculated as $2(T_p - T_o)$. The Peak Heat Index (PHI, mJ/mg/° C) was calculated by the ratio $\Delta H / (T_p - T_c)$ as described by Krueger et al (1987). Differences in the magnitude of these parameters between hybrids, as well as between temperature and moisture levels were inferred to reflect differences in quality over time.

v. Near infrared transmittance (NIR)

At every sampling period, samples were analyzed for chemical constituents using an Infratec 1229 Grain analyzer (Tecator, Sweden) in the ISU Grain Quality Lab. Results of % oil, protein and starch contents were measured on the basis of the standard 15 % moisture corn.

Statistical analysis.

Analysis of variance and comparisons among treatments were computed using the Statistical Analysis System (SAS Institute, Cary, NC). The differences between hybrids and quality changes over time for all storage conditions (temperature and moisture) were computed at the 5 % probability level. However, it was deemed impractical to carry out pair-wise comparisons due to the huge number of combinations that would need a very large number of pair-wise comparisons. Due to the large number of factors and the number of dependent variable tested pair- wise comparisons were not done. For the same reason, interactions were limited to two factor effects. The three and four factor interactions were not considered.

RESULTS AND DISCUSSION

Dry matter loss (DML)

DML results are summarized in Figs 1 (a) to 1 (d). Complete data are shown in Appendix B. Table 1 attached shows a summary of the mean DML.

The 27 $^{\circ}$ C storage temperature had more DML than 10 $^{\circ}$ C storage. The 15 % moisture corn had higher % DML than the 12 % moisture corn at both the 10 and 27 $^{\circ}$ C storage temperature levels. In addition, the 15 % moisture corn at 10 $^{\circ}$ C had slightly more DML than the 12 % moisture corn at both 10 and 27 $^{\circ}$ C storage temperatures.

Hybrids were different at $\alpha = 0.05$. The high oil corn had the highest % DML and the waxy corn had the lowest. The oil treated corn had higher DML than the control. This does not show any preservative effects of the oil treatment, on the basis of DML.

Damage kernel total (DKT)

DKT results are summarized in Figs 2 (a) to 2 (d). Complete data are shown in Appendix C. Table 2 attached shows a summary for DKT. Hybrids were different at $\alpha =$ 0.05.

At 10 $^{\circ}$ C storage there were no differences between the 12 % and 15 % moisture corn. At 27 $^{\circ}$ C storage most hybrids had more DKT on 15 % than on 12 % moisture corn. The high oil corn had the highest DKT, especially on the 15 % moisture corn, than all the other hybrids. The food grade corn had similar DKT at all storage conditions. The oil treated corn had less DKT than the control indicating preservative effects of oil treatment.

Fat acidity value (FAV)

FAV results are summarized in Figs 3 (a) to 3 (d). Complete data are shown in Appendix D. Fat acidity measures the amount of free fatty acids in 100 g of grain.

Table 1 attached show a summary of mean FAV. Hybrids were different at $\alpha = 0.05$. At 10 ° C storage, there were no differences between means for 12 and 15 % moisture levels, but at 27 ° C the means were different between moistures levels. At 27 ° C storage temperature, the mean FAV were higher than at 10 ° C storage.

At 27 ° C storage the high oil corn had the higher FAV, indicating relatively higher deterioration than the other hybrids. These findings concur with findings by Ileleji et al (2002) who found faster deterioration of high oil corn than normal oil corn, as indicated by FAV, on a high moisture (19 and 22 %) short- term storage study.

The oil treated corn had lower FAV than the control, indicating some preservative effects of oil treatment.

Differential Scanning Calorimetry (DSC) – Onset temperature (T_o)

Complete data for T_o are included as Appendix E. Table 4 attached shows a summary for T_o. There were no differences between temperature and / or moisture levels implying that conditions of storage have no effect on To. These findings concur with findings by Svendsen (1999) who observed no differences in the pasting properties of value- enhanced corn hybrids except when corn hybrids were different. Yamin (1999) also observed no significant differences between thermal properties of fresh and corn kernels stored over a long time (from 1989 to 1995). Yuan et al (1993) concluded that T_o is influenced by the number of the long chains in the amylopectin molecules, and that the environment had no influence on the T_o. Generally, the findings in this experiment concur fairly well with the findings by the researchers cited above. Conditions of storage also had no effect on the gelatinization range (R) and the peak height index (PHI), both of which are determined using the DSC procedure. Similarly, these properties of starch do not appear to be influenced by storage conditions.

Near infrared transmittance (NIR) – Oil Content

Complete NIR results are shown in Appendix F. Table 5 attached is a summary if results. The conditions of storage had no effect on the oil content. The high oil corn had significantly higher oil than the other corn hybrids. The other specialty corn hybrids (Ha, Fg and Wx) were not different. The control and the oil treated corn were not different and had less oil than all the others. This trend was the same at all storage conditions and at all sampling times, indicating that storage conditions or time of storage had no effect on the oil content as measured by the use of near infrared transmittance (Infratec 1229, Tecator, Sweden).

Trends on the other properties measured using NIR (starch, protein and grain density) did not show any variability between storage conditions or time in storage, implying that these properties are not influenced by the conditions of storage.

CONCLUSIONS

The following conclusions can be drawn from the research:

i. For each hybrid, corn stored at 27 ^{o} C deteriorated faster than that stored at 10 ^{o} C.

ii. At the 27 ^{o} C temperature the 15 % moisture corn deteriorated faster than the 12 % moisture corn.

iii. At 10 ^{o} C storage temperature, there were no differences between the 12 and 15 % moisture corn.

iv. High oil, high amylose and food grade corn hybrids (in that order) deteriorated faster than the control corn.

v. Waxy corn hybrids deteriorated slower than the control.

vi. Although DML showed no significant difference, the oil treated corn deteriorated slower than the control, indicating preservative effects of the oil treatment.

REFERENCES

AACC. 1999. Approved Methods, 9th Ed. Vol. 1. Fat acidity – Rapid method for corn. St Paul MN: AACC

Al- Yahya S A, C J Bern, M K Misra and T B Bailey. 1993. Carbon dioxide evolution of fungicide-treated high- moisture corn. Transactions of the ASAE 36(5): 1417 – 1422.

Bern, C. J., J. L. Steele, R. V. Morey. 2002. Shelled corn CO2 evolution and storage time to 0.5 % dry matter loss. Applied Engineering in Agriculture 17: (6).

Braun, J. V and J. D. Braun. 1958. A simplified method for preparing solutions of glycerol and water for humidity control. Corrosion 14: 17 – 18.

Chen Y. Y. 1997. Distribution of amylopectin branch chain-length and their correlations to physical properties of selected starches. MS Thesis. Iowa State University. Ames, Iowa. :11 – 28.

Cooke, D and M J Gidley. 1992. Loss of crystalline and molecular order during gelatinization: Origin of enthalpic transition. Carbohydrate Research 227: 103

Farm Source. 2002. http://www.farmsource.com/seedcatalog/productdetail.asp?product. Accessed 26th September 2002.

Food and Agricultural Organization. 1992. Maize in human nutrition. FAO Food & Nutrition Services. 25: P 2 – 35.

Green, J.G. 1961. High temperature storage of dry maize. PhD Dissertation. Iowa State University. Ames Iowa.

Hallauer, A. R. 1994. Specialty corns. CRC Press, Inc. Boca Raton, CA. : 29 – 73

Ileleji, K. E., W. F. Wilcke, R. V. Morey. 2002. Relative storability of high- oil and Bt corn hybrids compared to conventional hybrids. ASAE Paper 016057. St Joseph, Michigan. ASAE.

Krueger, B R, C A Knutson, G E Inglett, and C E Walker. 1987. A differential scanning calorimetry study on the effect of annealing on gelatinization behavior of cornstarch. Journal of Food Science. 52: 715 – 718.

Potter N N. 1968. Food science. AVI Publishing Co Inc Westport Connecticut: 98 – 123

Rudunukin I H, P J White, C J Bern and T B Bailey. 1998. A modified method for determining free fatty acids from small soybean oil sample sizes. Journal of American Oil Chemists Society. 75 (5): 563 – 568.

Saul, R. A. and J. L. Steele. 1966. Why damaged shelled corn costs more to dry. Agricultural Engineering 47 (6): 326 – 329

Steel, J. L., R. A. Saul, W. V. Hukill. 1969. Deterioration of shelled corn as measured by carbon dioxide production. Transactions of the ASAE 12: (5) 685 – 689.

Stevens, D J and G A H Elton.1971. Thermal properties of starch/water system. Part 1. Measurement of heat of gelatinization by differential scanning calorimetry. Starch / Staerke 23: 8 – 11.

Wilson Seeds, 2002. http://www.wilsonseeds.com/agronomy.asp. Accessed 25th September 2002.

Yamin, F. F. 1997. Genetic enhancement of starch in corn. MS Thesis. Iowa State University. Ames Iowa. : 9 – 35.

Yamin, F F, L Svendsen, P J White. 1997. Thermal properties of cornstarch extraction intermediates by Differential Scanning Calorimetry. American Association of Cereal Chemists, Inc. Vol. 74, (4) : 407 – 411.

Yamin, F F, M. Lee, L. M. Pollak, P. J. White. 1999. Thermal Properties of Starch in Corn Variants Isolated After Chemical Mutagenesis of Inbred Line B73. American Association of Cereal Chemists, Inc. Vol. 76 (2): 175 – 181.

Yuan R C, D B Thompson and C D Boyer. 1993. Fine structure of amylopectin in relation to gelatinization and retrogradation behavior of maize starches from three Wx- containing genotypes in two inbred lines. Cereal Chem. 74: 81 – 89.

USA Grain Council. 2000 / 2002. Value- enhanced quality report.

Winston P W, D H Bates. 1960. Saturated Solutions for the control of humidity in biological research. Ecology, Department of Biology, University of Colorado 41: 232 – 237.

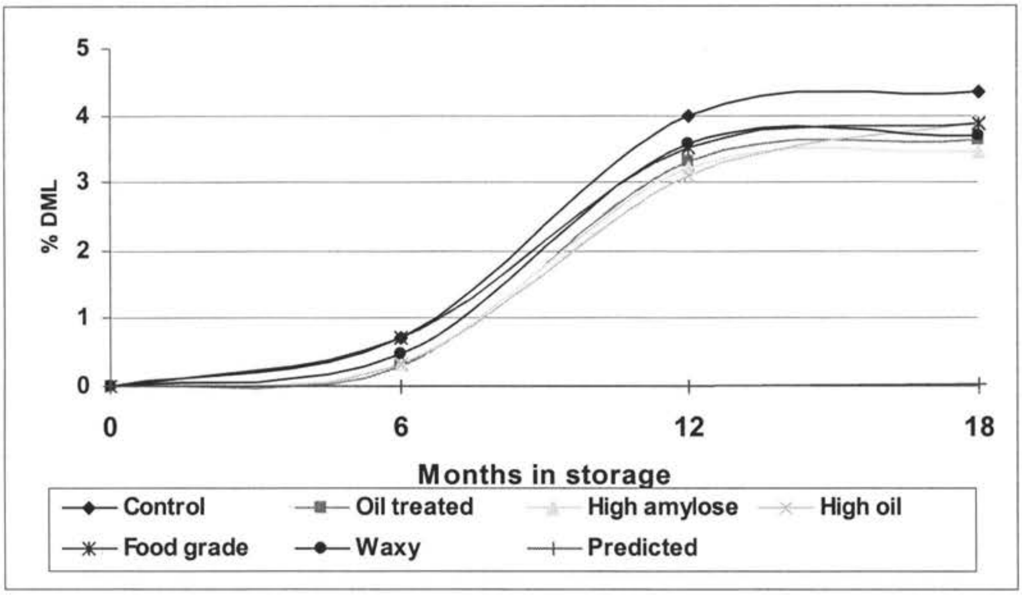

Fig 1 (a): Dry matter loss for 10 ° C, 12 % moisture storage (averages of 3 replications)

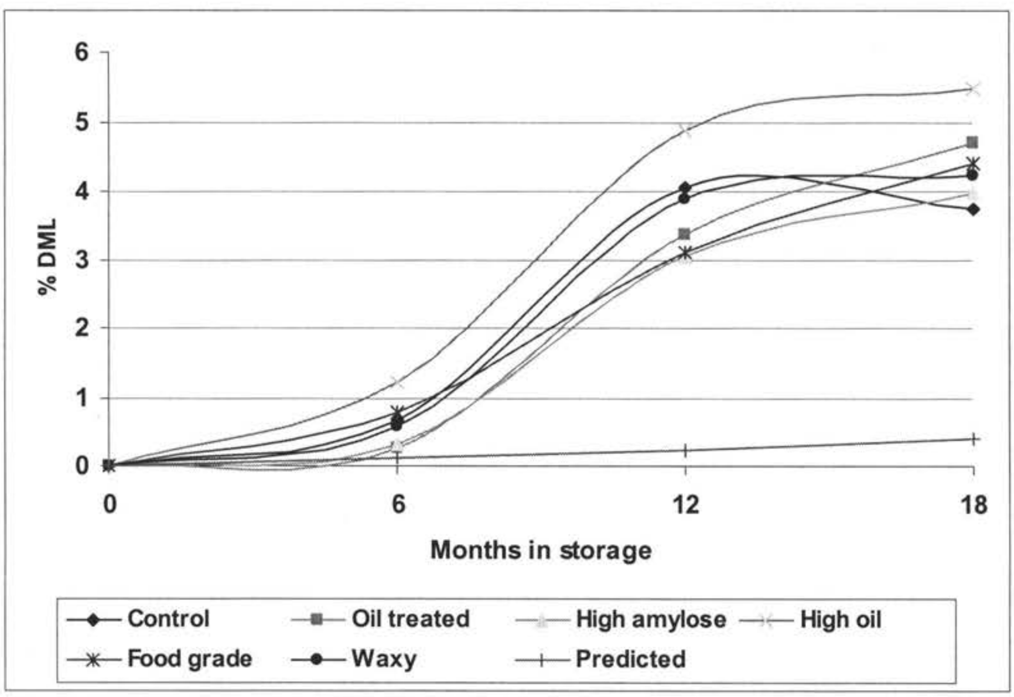

Fig 1 (b): Dry matter loss for 10 ° C, 15 % moisture storage (average of 3 replications)

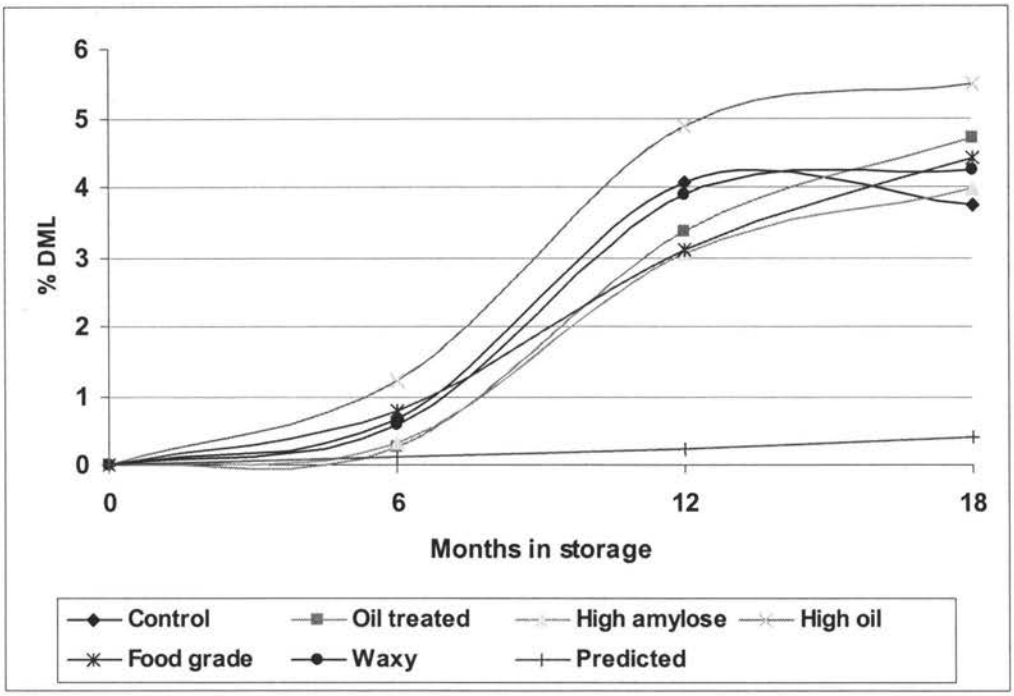

Fig 1 (c): Dry matter loss for 27 ° C, 12 % moisture storage (average of 3 replications)

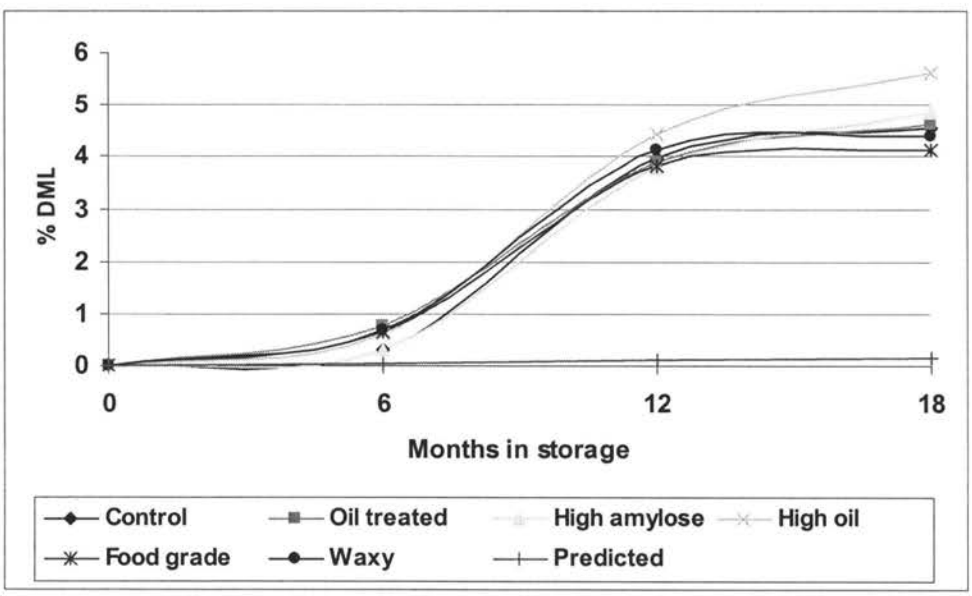

Fig 1 (d): Dry matter loss for 27 ° C, 15 % moisture storage (average of 3 replications).

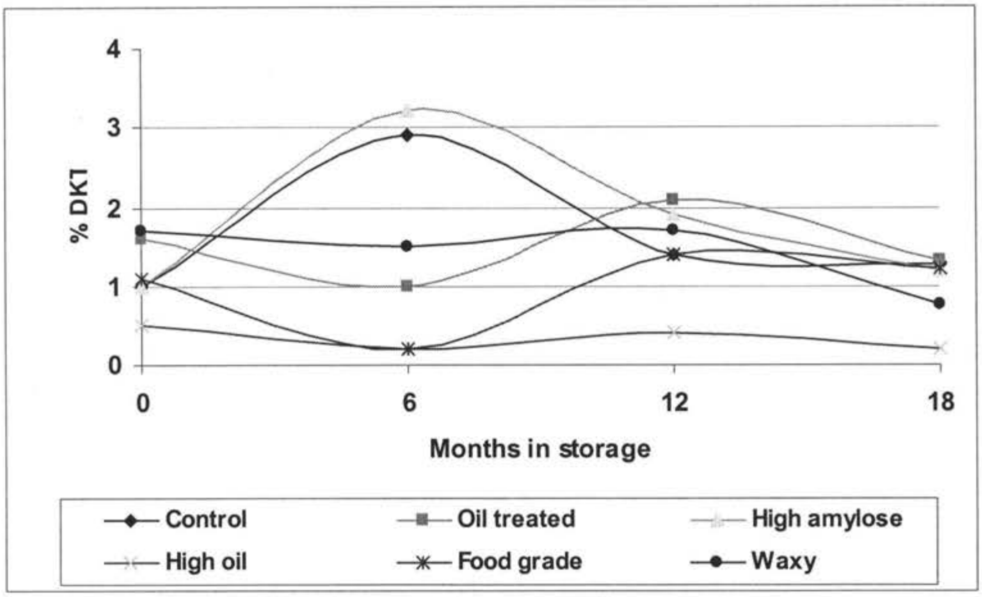

Fig 2 (a): Damaged kernels total for 10 ° C, 12 % moisture storage (average of 3 replications)

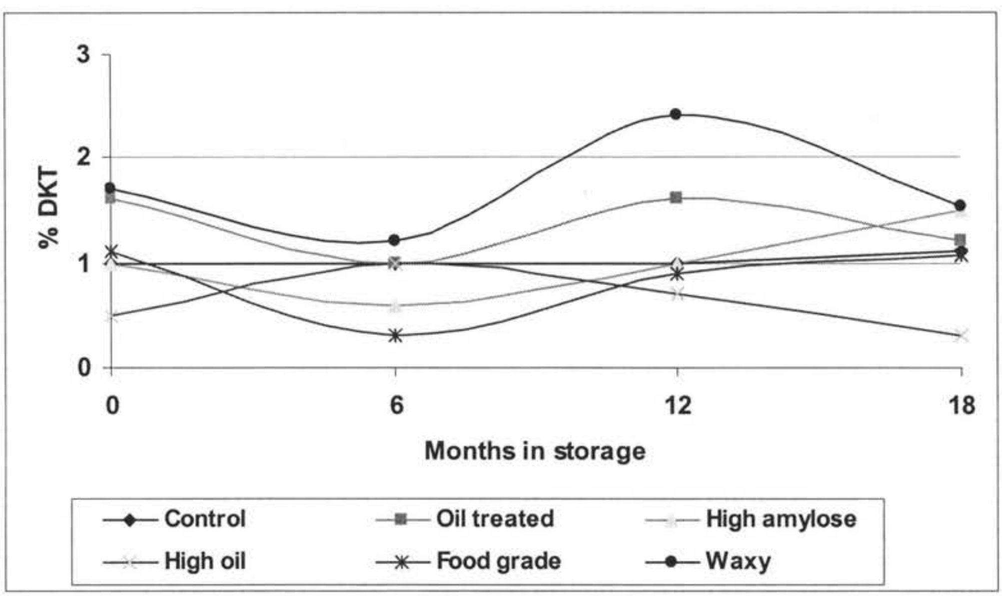

Fig 2 (b): Damaged kernel total for 10 ° C, 15 % moisture storage (average of 3 replications)

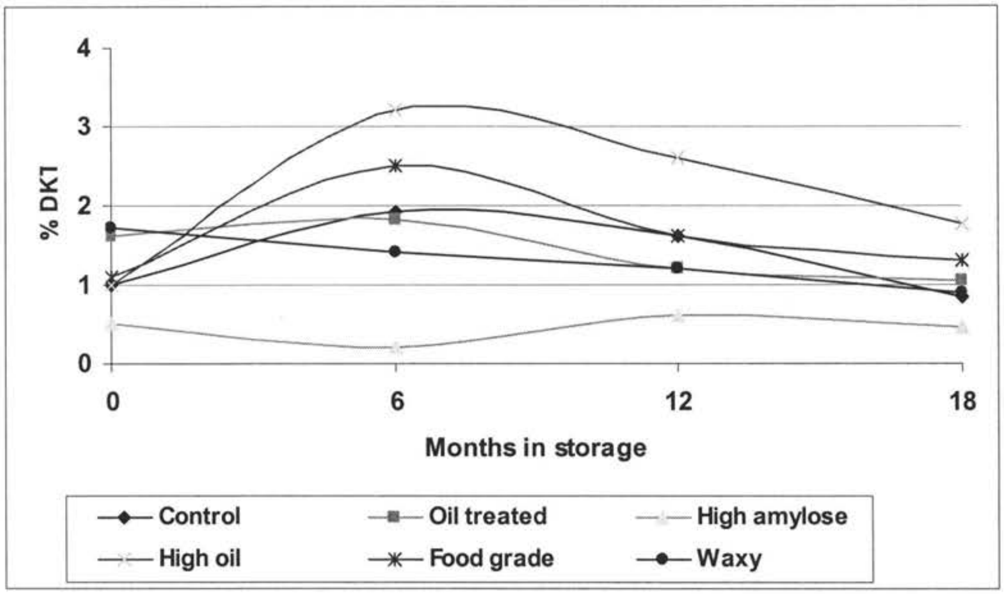

Fig 2 (c): Damaged kernel total for 27 ° C, 12 % moisture storage (average of 3 replications)

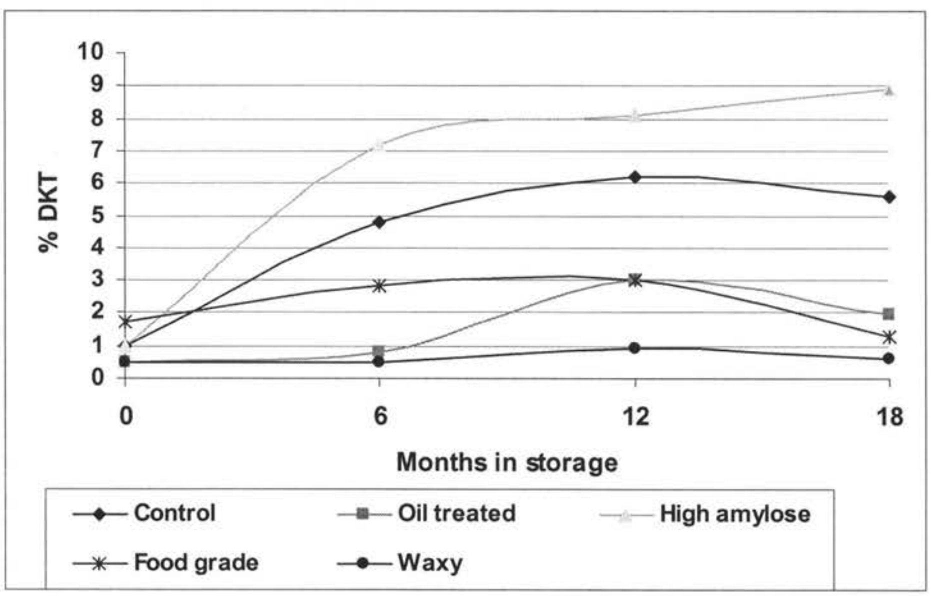

Fig 2 (d): Damaged kernel total for 27 ° C, 15 % moisture storage, excluding the high oil corn which had 63 % DKT (average of 3 replications)

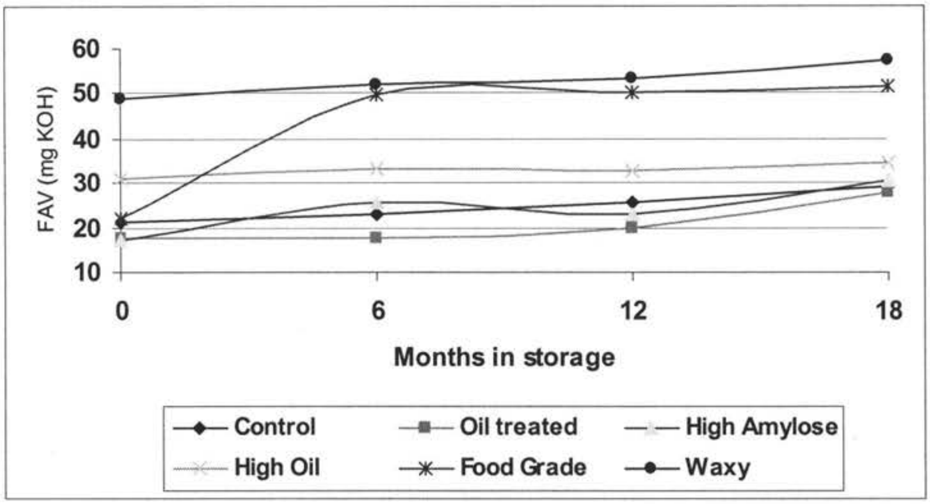

Fig 3 (a): Fat acidity value for 10 ° C, 12 % moisture storage (average of 3 replications)

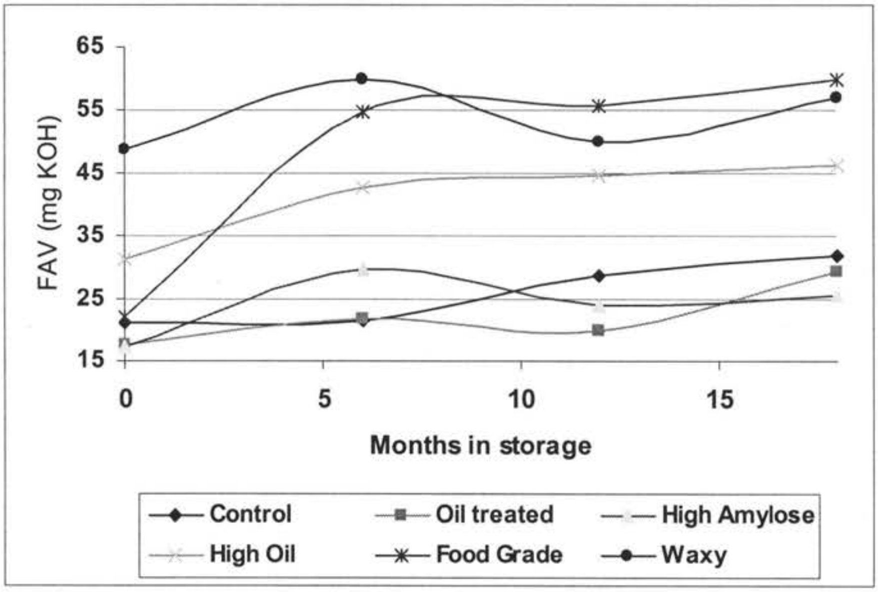

Fig 3 (b): Fat acidity value for 10 ° C, 15 % moisture storage (average of 3 replications)

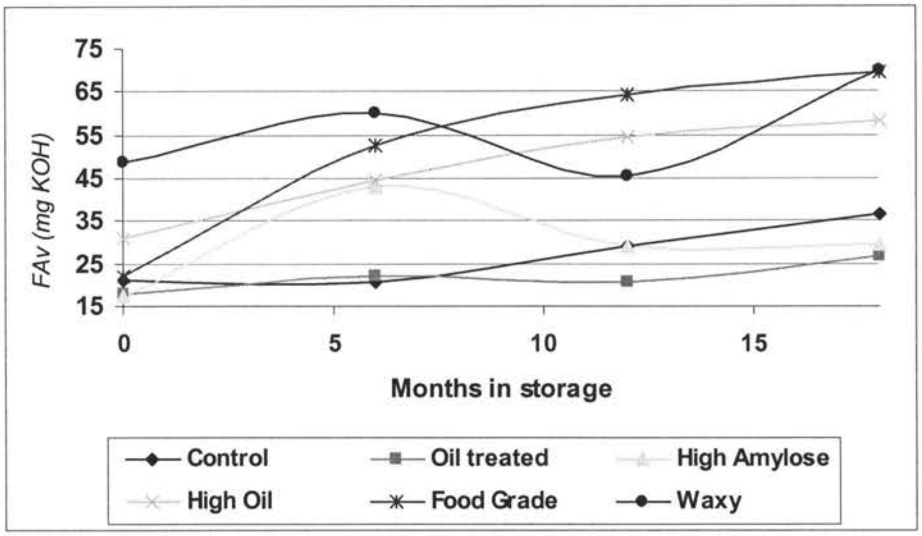

Fig 3 (c): Fat acidity value for 27 ° C, 12 % moisture storage (average of 3 replications)

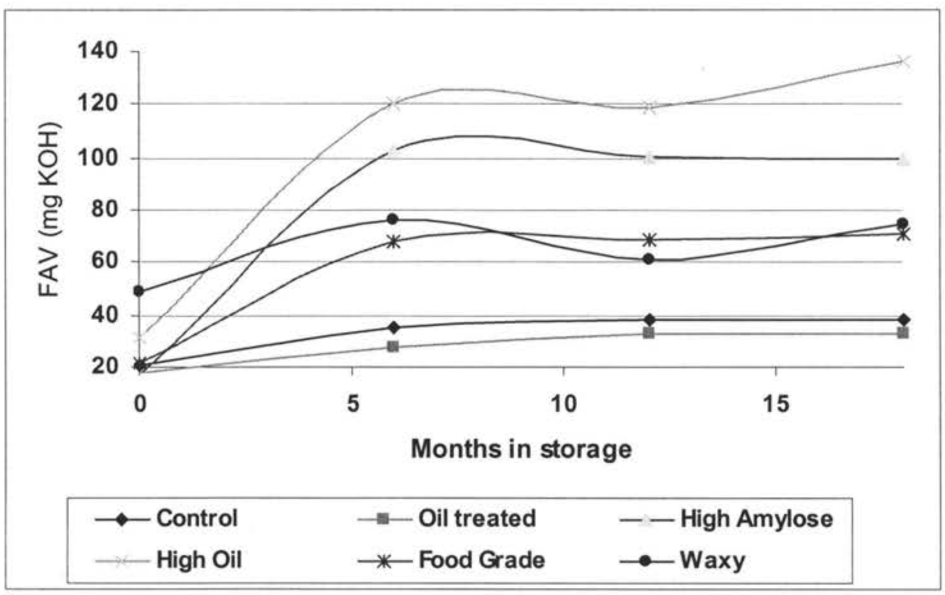

Fig 3 (d): Fat acidity value for 27 ° C, 15 % moisture storage (average of 3 replications)

Table 1: Summary of means * for cumulative dry matter loss (DML) after 18 months storage for all hybrids at 4 storage conditions.

	10 °C		27 °C	
	12 %	15 %	12 %	15 %
Ho	2.59 d	3.98 b	3.58 c	7.81 a
Ha	2.38 c	2.96 b	3.10 b	5.97 a
C + O	2.41 d	3.30 b	3.09 c	4.79 a
Fg	2.69 c	3.11 b	2.70 c	4.76 a
C	3.03 b	2.41 c	2.94 b	4.61 a
Wx	2.58 d	3.03 c	3.29 b	3.60 a

* Means with the same letter within a row are not significantly different at $\alpha = 0.05$.

Table 2: Summary of means * for damaged kernels total (DKT) after 18 months storage for all hybrids at the 4 storage conditions.

	10 °C		27 °C	
	12 %	15 %	12 %	15 %
Ho	1.2 b	1.5 b	1.3 b	62.5 a
Ha	1.2 c	1.1 c	1.8 b	8.9 a
C	1.3 b	1.1 b	0.8 b	5.6 a
C + O	1.3 b	1.2 b	1.0 b	2.0 a
Wx	0.8 b	1.5 a	0.9 b	1.5 a
Fg	0.2 b	0.3 b	0.5 a	0.6 a

* Means with the same letter within a row are not significantly different at $\alpha = 0.05$.

Table 3: Summary of means * for fat acidity value (FAV) after 18 months storage for all hybrids at the 4 storage conditions.

	10 °C		27 °C	
	12 %	15 %	12 %	15 %
Ho	33.5 [d]	44.5 [c]	52.3 [b]	125.0 [a]
Ha	26.3 [c]	26.4 [c]	33.9 [b]	100.8 [a]
Wx	54.3 [c]	55.6 [c]	58.4 [b]	70.3 [a]
Fg	50.4 [c]	57.2 [b c]	62.1 [b]	69.1 [a]
C	26.0 [b]	27.4 [b]	28.7 [b]	37.1 [a]
C + O	21.7 [c]	23.5 [b c]	23.1 [b]	31.0 [a]

* Means with the same letter within a row are not significantly different at $\alpha = 0.05$.

Table 4: Summary of means * for the gelatinization temperature (T_o) as measured by differential scanning Calorimetry (DSC) after 18 months storage for all hybrids at the 4 storage conditions.

	10 °C		27 °C	
	12 %	15 %	12 %	15 %
C	66.6 [a]	67.5 [a]	65.8 [a]	66.2 [a]
C + O	67.5 [b]	68.2 [b]	68.2 [b]	67.8 [b]
Ha	66.9 [c]	65.6 [c]	67.0 [c]	65.7 [c]
Ho	65.3 [d]	65.9 [d]	65.1 [d]	64.4 [d]
Fg	64.2 [d]	64.2 [d]	64.9 [d]	65.3 [d]
Wx	66.4 [e]	64.5 [e]	62.2 [e]	64.8 [e]

* Means with the same letter within a row are not significantly different at $\alpha = 0.05$.

Table 5: Summary of means * for oil content (%) as measured by near infrared (NIR) transmittance after 18 months storage for all hybrids at the 4 storage conditions.

	10 ° C		27 ° C	
	12 %	15 %	12 %	15 %
Ho	1.2 [b]	1.5 [b]	1.3 [b]	62.5 [a]
Ha	1.2 [c]	1.1 [c]	1.8 [b]	8.9 [a]
C	1.3 [b]	1.1 [b]	0.8 [b]	5.6 [a]
C + O	1.3 [b]	1.2 [b]	1.0 [b]	2.0 [a]
Wx	0.8 [b]	1.5 [a]	0.9 [b]	1.5 [a]
Fg	0.2 [b]	0.3 [b]	0.5 [a]	0.6 [a]

* Means with the same letter within a row are not significantly different at $\alpha = 0.05$.

GENERAL CONCLUSION

Storage is an essential component of crop production practices. Temperature and kernel moisture of storage decide how long the produce can be stored before appreciable loss of quality could be realized. This study strived to determine the loss of quality for commodity and specialty corn hybrids stored at low- moisture, over a long (over one year) time and at different temperatures.

Acknowledgements.

I would like to express my gratitude to my major professor Dr Carl J Bern for his advice and guidance. I would also like to thank Dr Jenni L. Briggs for her assistance on the DSC tests and for the use of her Lab. Special thanks go to Dr Ted B. Bailey for his untiring effort during the analyze of data. Last, but by no means least, I would also like to thank Dr Tom Brumm and Dr Graeme Quick for serving in my POS committee. In addition I appreciate the contribution of other staff members such as Dr Pam J White, Dr Rezaei Karamatollah (Food Science) and Mr Glenn Rippke (Grain quality lab) for the much needed assistance.

Special thanks also go to my family for their support and understanding, my mother and siblings for their effort to assist my wife and children to cope during my absence. The list is endless and to those I didn't single out, thank you all.

APPENDIX A - CALCULATIONS

Specific gravity (SG) of glycerol = 1.261 and for water SG = 1.000 was used in the calculations.

1. For the 58 %Relative Humidity (RH).

   Glycerol / water solution SG = 1.194, volume of solution = 2.43 L

   Let volume of water is X, and Glycerol volume is Y.

   Total volume X + Y = 2.43 L. So volume of water = 2.43 –Y

   (2.43 – Y) + 1.261 Y = 2.43 (1.194)

   2.43 + 0.261 Y = 2.90142

   Y = 1.806 L.

   By difference X = 0.624 L   Ratio of Water: Glycerol = 1: 2.89

2. For the 76 % Relative Humidity

   Glycerol / water solution SG = 1.148, volume of solution = 2.43 L

   Let volume of water is X, and Glycerol volume is Y.

   Total volume X + Y = 2.43 L. So volume of water = 2.43 –Y

   (2.43 – Y) + 1.261 Y = 2.43 (1.148)

   2.43 + 0.261 Y = 2.78964

   Y = 1.378 L.

   By difference X = 1.052 L   Ratio of Water: Glycerol = 1: 1.31

APPENDIX B – RAW DATA FOR DRY MATTER LOSS (% DML)

Table B 1: DML raw data for all 6 hybrids at 4 storage conditions over 18 months

		Dec 00				Jun 01				Dec 01				Jun 02			
Hybrid		Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
Control	LL	0.00	0.00	0.00	0.00	0.98	0.53	0.62	0.71	4.00	3.02	5.00	4.01	4.66	3.14	5.32	4.37
	LH					0.01	0.06	0.22	0.10	3.55	3.18	3.47	3.40	4.15	3.54	3.52	3.74
	HL					0.40	0.27	0.27	0.31	3.47	4.69	3.77	3.98	3.77	3.83	5.98	4.53
	HH					1.24	0.74	1.27	1.08	5.95	4.33	7.95	6.08	5.97	5.13	8.93	6.68
Oil treated	LL	0.00	0.00	0.00	0.00	0.02	0.49	0.42	0.31	3.12	3.48	3.31	3.30	3.46	3.83	3.60	3.63
	LH					2.60	0.27	0.27	1.05	5.75	3.49	3.22	4.15	6.34	3.94	3.78	4.69
	HL					1.68	0.37	0.22	0.76	4.86	4.02	2.80	3.89	5.26	4.67	3.91	4.61
	HH					0.48	3.10	0.80	1.46	6.05	7.05	5.25	6.12	7.60	7.18	5.60	6.79
High amylose	LL	0.00	0.00	0.00	0.00	0.15	0.96	0.48	0.53	2.95	3.17	3.38	3.17	2.97	3.68	3.66	3.44
	LH					2.98	0.23	0.45	1.22	3.38	3.67	4.03	3.69	4.17	3.63	4.09	3.96
	HL					0.26	1.06	0.68	0.67	2.71	4.56	4.05	3.77	3.18	6.99	4.40	4.86
	HH					5.50	2.70	1.17	3.12	5.82	7.65	6.65	6.71	7.24	7.98	9.05	8.09
High Oil	LL	0.00	0.00	0.00	0.00	0.16	0.98	0.49	0.54	2.76	3.98	3.27	3.34	3.00	4.38	4.34	3.91
	LH					2.99	0.24	0.47	1.23	7.99	3.39	4.30	5.23	8.51	3.52	4.42	5.48
	HL					0.27	1.07	0.69	0.68	3.84	5.82	3.72	4.46	5.65	7.29	3.94	5.63
	HH					5.60	2.80	2.20	3.53	10.65	9.74	8.37	9.59	10.92	9.87	10.38	10.39
Food grade	LL	0.00	0.00	0.00	0.00	0.98	0.75	0.37	0.70	3.88	3.57	3.12	3.52	4.08	3.84	3.66	3.86
	LH					0.23	0.50	1.65	0.79	3.54	4.16	4.62	4.11	3.72	4.74	4.80	4.42
	HL					0.16	0.93	0.09	0.39	3.81	4.30	2.58	3.56	4.29	4.83	3.27	4.13
	HH					0.98	2.70	0.07	1.25	6.83	6.63	4.56	6.01	8.27	6.69	6.13	7.03
Waxy	LL	0.00	0.00	0.00	0.00	0.37	0.53	0.52	0.47	3.64	3.41	3.66	3.57	3.72	3.48	3.85	3.68
	LH					0.98	1.05	0.34	0.79	4.00	4.23	4.01	4.08	4.25	4.37	4.03	4.22
	HL					0.50	1.35	0.25	0.70	4.65	4.85	4.90	4.80	4.94	3.27	4.92	4.38
	HH					0.29	0.09	1.87	0.75	4.14	3.27	6.88	4.76	4.33	3.46	8.07	5.29

Key: LL = 10 °C, 12 % mc; HL = 27 °C, 12 % mc; LH = 10 °C, 15 % mc; HH = 27 °C, 15 % mc

APPENDIX C – RAW DATA FOR DAMAGED KERNEL TOTAL (DKT)

Table C 1: DKT raw data for all 6 hybrids at 4 storage conditions over 18 months

Hybrid		Dec 00 % DKT	Jun 01 % DKT	Dec 01 % DKT	Jun 02 Rep 1	Jun 02 Rep 2	Jun 02 Rep 3	Jun 02 Mean
Control	LL	1.00	2.90	1.40	1.00	1.40	1.40	1.27
	LH		1.00	1.00	1.50	0.90	0.90	1.10
	HL		1.90	1.60	0.50	0.90	1.10	0.83
	HH		4.80	6.20	1.40	2.10	13.20	5.57
Oil treated	LL	1.60	1.00	2.10	1.00	1.50	1.50	1.33
	LH		1.00	1.60	1.00	0.90	1.70	1.20
	HL		1.80	1.20	1.00	1.00	1.10	1.03
	HH		0.80	3.00	3.30	1.90	0.70	1.97
High amylose	LL	1.10	0.20	0.90	1.40	1.30	1.00	1.23
	LH		0.30	1.00	0.90	1.00	1.30	1.07
	HL		0.60	2.60	2.40	1.60	1.30	1.77
	HH		7.20	8.10	1.20	23.20	2.30	8.90
High Oil	LL	1.00	3.20	1.40	1.50	1.20	0.90	1.20
	LH		3.20	1.90	1.50	1.30	1.70	1.50
	HL		2.50	1.60	0.90	2.20	0.80	1.30
	HH		58.20	56.60	60.80	58.50	68.10	62.47
Food grade	LL	0.50	0.20	0.40	0.20	0.30	0.10	0.20
	LH		1.00	0.70	0.40	0.20	0.30	0.30
	HL		0.20	0.60	0.60	0.20	0.60	0.47
	HH		0.50	0.90	0.30	1.50	0.10	0.63
Waxy	LL	1.70	1.50	1.70	0.40	0.90	1.00	0.77
	LH		1.20	2.40	1.90	1.40	1.30	1.53
	HL		1.40	1.20	1.10	0.80	0.80	0.90
	HH		2.80	3.00	1.90	0.80	1.80	1.50

Key: LL = 10 ° C, 12 HL = 27 ° C, 12 % mc
LH = 10 ° C, 15 HH = 27 ° C, 15 % mc

NB: Samples pooled in Dec 00, Jun 01 and Dec 01, but not in Jun 02

APPENDIX D – RAW DATA FOR FAT ACIDITY VALUE (FAV)

Tabble D 1: FAV (milligrams of KOH/100 g corn) raw data for all 6 hybrids, at 4 storage conditions over 18 months

		Dec 00				Jun 01				Dec 01				Jun 02			
Hybrid		*Rep 1*	*Rep 2*	*Rep 3*	*Mean*	*Rep 1*	*Rep 2*	*Rep 3*	*Mean*	*Rep 1*	*Rep 2*	*Rep 3*	*Mean*	*Rep 1*	*Rep 2*	*Rep 3*	*Mean*
Control	*LL*	23.01	19.64	20.20	20.95	22.42	22.98	23.54	22.98	25.84	26.40	25.28	25.84	29.21	28.09	30.34	29.21
	LH					21.91	20.79	21.35	21.35	26.97	29.78	29.78	28.84	28.09	33.71	34.27	32.02
	HL					21.32	20.20	20.76	20.76	29.78	28.09	28.65	28.84	35.39	35.96	38.50	36.62
	HH					35.39	37.08	32.02	34.83	37.08	37.08	39.89	38.02	37.36	38.34	39.66	38.45
Oil treated	*LL*	16.85	17.42	18.54	17.60	17.98	16.85	17.98	17.60	18.54	19.10	21.35	19.66	26.79	29.57	26.82	27.73
	LH					21.35	21.35	21.91	21.54	19.10	19.66	20.22	19.66	29.78	28.09	30.34	29.40
	HL					21.79	21.23	22.91	21.98	20.07	21.18	20.62	20.62	26.40	26.97	26.97	26.78
	HH					27.00	28.12	27.00	27.37	33.15	32.02	32.58	32.58	29.78	34.27	35.39	33.15
High amylose	*LL*	17.49	16.37	18.06	17.31	20.74	31.95	24.10	25.60	23.03	22.47	23.60	23.03	27.53	33.15	30.34	30.34
	LH					29.21	29.21	30.34	29.59	24.72	24.16	23.03	23.97	25.28	26.97	24.72	25.66
	HL					32.62	49.49	46.68	42.93	30.45	25.28	32.02	29.25	28.09	29.78	30.90	29.59
	HH					101.12	103.93	103.37	102.81	91.37	109.30	99.78	100.15	100.00	98.88	99.44	99.44
High Oil	*LL*	32.66	29.84	30.97	31.16	34.79	31.43	33.67	33.30	32.02	31.46	34.83	32.77	34.83	34.27	34.27	34.46
	LH					44.38	42.13	41.57	42.69	44.94	44.38	44.94	44.75	42.70	47.19	48.31	46.07
	HL					46.02	44.33	42.65	44.33	55.06	52.81	55.06	54.31	57.87	58.43	58.43	58.24
	HH					121.48	118.67	119.80	119.98	120.09	117.85	117.41	118.45	132.58	138.20	138.20	136.33
Food grade	*LL*	23.01	21.32	21.32	21.88	48.31	48.31	52.81	49.81	44.94	46.07	58.99	50.00	43.77	47.14	63.41	51.44
	LH					52.81	47.19	64.04	54.68	46.07	63.48	57.87	55.81	59.55	64.61	58.99	61.05
	HL					53.93	51.69	52.25	52.62	62.29	69.02	61.17	64.16	72.47	69.66	66.29	69.47
	HH					67.34	74.64	62.29	68.09	77.53	65.17	62.36	68.35	70.22	71.91	70.79	70.97
Waxy	*LL*	48.88	48.31	48.88	48.69	51.40	50.84	53.63	51.96	53.63	51.96	54.75	53.45	58.99	56.74	56.18	57.30
	LH					57.30	56.18	66.29	59.92	51.12	49.44	49.37	49.98	56.74	56.74	57.30	56.93
	HL					61.80	57.30	61.24	60.11	46.07	44.94	44.94	45.32	69.10	69.66	70.79	69.85
	HH					80.63	73.91	73.35	75.96	64.04	55.62	62.36	60.67	74.72	74.16	74.72	74.53

Key: *LL = 10 ° C, 12 % mc* | *HL = 27 ° C, 12 % mc*
LH = 10 ° C, 15 % mc | *HH = 27 ° C, 15 % mc*

APPENDIX E – DIFFERENTIAL SCANNING CALORIMETRY

Table E 1: Gelatinization onset temperature (T_o, °C) raw data for all 6 hybrids, at 4 storage conditions over 18 months

Hybrid		Dec 00 Rep 1	Dec 00 Rep 2	Dec 00 Rep 3	Dec 00 Mean	Jun 01 Rep 1	Jun 01 Rep 2	Jun 01 Rep 3	Jun 01 Mean	Dec 01 Rep 1	Dec 01 Rep 2	Dec 01 Rep 3	Dec 01 Mean	Jun 02 Rep 1	Jun 02 Rep 2	Jun 02 Rep 3	Jun 02 Mean
Control	LL	68.2	66.9	67.8	67.6	66.5	.	65.7	66.1	67.5	65.6	66.7	66.6	66.6	67.5	68.2	67.4
	LH					67.1	.	68.0	67.6	66.8	67.5	67.1	67.1	67.9	67.6	67.2	67.6
	HL					68.8	65.6	61.4	65.3	67.9	66.5	63.5	66.0	65.7	66.4	66.2	66.1
	HH					.	65.2	66.7	66.0	64.3	66.2	66.8	65.8	68.0	66.4	66.1	66.8
Oil treated	LL	67.0	68.9	67.4	67.8	65.4	67.5	67.1	66.7	66.5	66.8	67.2	66.8	68.5	69.3	68.8	68.9
	LH					68.5	67.8	67.7	68.0	67.8	67.5	66.7	67.3	70.1	68.5	69.0	69.2
	HL					69.0	71.7	67.8	69.5	68.2	70.2	67.6	68.7	67.5	64.4	67.1	66.3
	HH					70.0	67.2	67.7	68.3	68.1	67.6	68.4	68.0	65.7	66.6	67.7	66.7
High	LL	67.1	67.2	65.2	66.5	64.9	64.8	64.9	64.9	65.8	66.7	68.9	67.1	68.4	66.7	66.1	67.1
amylose	LH					64.9	62.6	66.5	64.7	65.1	63.2	67.1	65.1	66.0	64.1	70.5	66.9
	HL					62.3	65.2	68.4	65.3	63.2	66.5	69.0	66.2	62.8	68.1	67.9	66.3
	HH					64.6	61.4	61.5	62.5	65.1	62.8	62.6	63.5	68.3	68.9	66.2	67.8
High Oil	LL	67.5	67.9	67.0	67.5	63.4	65.6	64.5	64.5	63.9	66.5	64.5	65.0	68.6	65.5	65.3	66.5
	LH					61.9	64.5	.	63.2	67.1	65.6	66.5	66.4	64.8	71.6	67.8	68.1
	HL					66.3	64.4	64.0	64.9	63.5	63.8	65.9	64.4	67.4	67.0	63.6	66.0
	HH					62.4	62.6	66.0	63.7	63.2	63.8	65.9	64.3	66.3	.	64.9	65.6
Food grade	LL	65.9	66.6	65.7	66.1	61.8	64.4	.	63.1	62.8	63.9	65.5	64.1	62.4	65.5	65.9	64.6
	LH					65.9	64.1	66.6	65.5	66.2	63.8	65.9	65.3	.	60.5	62.1	61.3
	HL					.	60.4	64.7	62.6	61.3	61.4	65.2	62.6	64.4	58.6	62.0	61.7
	HH					61.6	62.1	67.5	63.7	62.5	63.5	68.5	64.8	65.4	63.7	73.0	67.4
Waxy	LL	66.1	66.8	66.0	66.3	71.4	65.9	65.7	67.7	69.5	67.5	66.4	67.8	66.1	64.2	61.0	63.8
	LH					65.8	68.9	63.8	66.2	66.2	67.5	63.5	65.7	62.3	62.0	60.4	61.6
	HL					.	62.5	59.8	61.2	63.5	62.8	60.3	62.2	64.4	62.3	.	63.4
	HH					64.6	.	68.9	66.8	65.5	64.8	67.6	66.0	61.7	61.9	62.1	61.9

Key: LL = 10 °C, 12 % mc; LH = 10 °C, 15 % mc; HL = 27 °C, 12 % mc; HH = 27 °C, 15 % mc

APPENEDIX E (cont.)

Table E 2: Gelatinization range (R) raw data for all 6 hybrids, at 4 storage conditions over 18 months

Hybrid		Dec 00 Rep 1	Dec 00 Rep 2	Dec 00 Rep 3	Dec 00 Mean	Jun 01 Rep 1	Jun 01 Rep 2	Jun 01 Rep 3	Jun 01 Mean	Dec 01 Rep 1	Dec 01 Rep 2	Dec 01 Rep 3	Dec 01 Mean	Jun 02 Rep 1	Jun 02 Rep 2	Jun 02 Rep 3	Jun 02 Mean
Control	LL	16.8	15.8	15.8	16.1	16.0	.	18.4	17.2	14.2	20.0	16.4	16.9	19.2	17.8	16.2	17.7
	LH					16.4	.	16.0	16.2	16.8	16.6	18.4	17.3	15.4	17.4	17.0	16.6
	HL					19.2	11.0	19.8	16.7	16.8	11.6	20.2	16.2	19.2	19.6	19.2	19.3
	HH					.	15.4	10.8	13.1	18.6	16.8	13.4	16.3	15.4	16.6	19.4	17.1
Oil treated	LL	16.2	15.2	17.0	16.1	15.2	16.0	17.4	16.2	14.0	19.4	15.4	16.3	14.4	14.2	14.8	14.5
	LH					15.2	15.6	13.4	14.7	18.8	18.0	17.4	18.1	12.2	13.8	14.2	13.4
	HL					14.6	20.4	16.6	17.2	18.0	13.2	16.6	15.9	13.8	16.8	18.0	16.2
	HH					13.6	18.4	18.8	16.9	15.0	15.6	16.2	15.6	21.2	18.8	17.0	19.0
High amylose	LL	15.6	16.8	20.2	17.5	18.2	21.2	12.0	17.1	18.4	18.6	11.8	16.3	13.6	17.4	18.2	16.4
	LH					22.0	25.0	19.6	22.2	22.0	23.4	16.8	20.7	18.6	21.4	11.2	17.1
	HL					25.6	21.6	14.4	20.5	26.0	19.2	13.6	19.6	15.2	13.2	17.8	15.4
	HH					22.0	28.8	27.4	26.1	22.2	26.2	25.6	24.7	13.2	16.0	19.6	16.3
High Oil	LL	14.8	17.4	19.6	17.3	20.2	19.4	21.8	20.5	19.8	19.4	24.0	21.1	13.8	18.8	20.4	17.7
	LH					26.2	23.0	.	24.6	19.2	23.8	20.6	21.2	22.0	14.2	15.2	17.1
	HL					19.2	24.4	22.6	22.1	26.6	24.4	23.2	24.7	13.6	22.8	24.2	20.2
	HH					26.4	27.8	20.8	25.0	26.0	24.2	21.8	24.0	20.0	.	23.4	21.7
Food grade	LL	16.8	17.0	20.0	17.9	24.2	21.2	.	22.7	23.4	23.4	18.6	21.8	24.2	18.0	20.8	21.0
	LH					22.0	23.0	21.6	22.2	20.6	24.0	21.8	22.1	.	32.0	27.4	29.7
	HL					.	21.0	22.8	21.9	30.4	29.0	22.2	27.2	24.6	24.0	28.8	25.8
	HH					19.0	18.0	16.6	17.9	30.2	26.6	16.8	24.5	22.4	25.4	20.0	22.6
Waxy	LL	22.0	21.8	23.0	22.3	15.8	15.8	15.6	15.7	13.4	10.6	16.4	13.5	22.6	20.4	30.2	24.4
	LH					13.2	15.4	12.6	13.7	10.4	10.2	14.8	11.8	26.8	26.6	30.4	27.9
	HL					.	24.0	18.4	21.2	23.6	24.0	19.8	22.5	25.8	29.6	.	27.7
	HH					21.0	.	16.4	18.7	22.0	25.4	19.6	22.3	30.8	29.4	27.8	29.3

Key: LL = 10 °C, 12 % mc; HL = 27 °C, 12 % mc; LH = 10 °C, 15 % mc; HH = 27 °C, 15 % mc

APPENDIX E – (cont.)

Table E 3: Peak height index (PHI) raw data for all 6 hybrids, at 4 storage conditions over 18 months

Hybrid		Dec 00 Rep 1	Dec 00 Rep 2	Dec 00 Rep 3	Dec 00 Mean	Jun 01 Rep 1	Jun 01 Rep 2	Jun 01 Rep 3	Jun 01 Mean	Dec 01 Rep 1	Dec 01 Rep 2	Dec 01 Rep 3	Dec 01 Mean	Jun 02 Rep 1	Jun 02 Rep 2	Jun 02 Rep 3	Jun 02 Mean
Control	LL	0.64	0.72	0.80	0.72	0.43	.	0.37	0.40	0.60	0.48	0.57	0.55	0.63	0.73	0.85	0.74
	LH					0.58	.	0.55	0.57	0.51	0.58	0.56	0.55	0.81	1.10	0.88	0.93
	HL					0.51	0.74	0.38	0.54	0.51	0.72	0.42	0.55	0.32	0.67	0.76	0.58
	HH					.	0.45	0.70	0.58	0.44	0.52	0.64	0.53	1.13	0.81	0.90	0.95
Oil treated	LL	0.74	0.79	0.66	0.73	1.04	0.98	0.98	1.00	0.93	0.68	0.80	0.80	1.02	1.07	1.08	1.06
	LH					0.55	0.73	0.81	0.70	0.45	0.58	0.62	0.55	1.06	1.07	1.09	1.07
	HL					0.94	1.09	0.65	0.89	0.64	0.99	0.68	0.77	1.09	1.06	0.86	1.00
	HH					0.81	0.66	0.57	0.68	0.77	0.79	0.72	0.76	0.72	0.91	0.87	0.83
High amylose	LL	0.51	0.41	0.35	0.42	0.40	0.56	0.81	0.59	0.40	0.61	0.85	0.62	0.47	0.47	0.32	0.42
	LH					0.38	0.33	0.37	0.36	0.41	0.36	0.48	0.42	0.34	0.34	0.84	0.51
	HL					0.37	0.45	0.75	0.52	0.39	0.52	0.77	0.56	0.69	0.61	1.02	0.77
	HH					0.34	0.32	0.31	0.32	0.35	0.35	0.33	0.34	0.36	0.66	0.63	0.55
High Oil	LL	0.59	0.45	0.34	0.46	0.65	0.21	0.40	0.42	0.65	0.54	0.36	0.52	0.80	0.62	0.28	0.57
	LH					0.33	0.43	.	0.38	0.73	0.38	0.44	0.52	0.52	0.97	0.47	0.65
	HL					0.53	0.54	0.56	0.54	0.39	0.38	0.39	0.39	0.44	0.60	0.57	0.54
	HH					0.35	0.28	0.37	0.33	0.34	0.34	0.40	0.36	0.63	.	0.58	0.61
Food grade	LL	0.63	0.43	0.54	0.53	0.30	0.30	.	0.30	0.33	0.31	0.44	0.36	0.52	0.54	0.40	0.49
	LH					0.43	0.41	0.40	0.41	0.47	0.39	0.40	0.42	.	0.13	0.22	0.18
	HL					.	0.39	0.40	0.40	0.23	0.24	0.41	0.29	0.62	0.45	0.40	0.49
	HH					0.37	0.36	0.49	0.41	0.28	0.36	0.50	0.38	0.51	0.46	0.41	0.46
Waxy	LL	0.63	0.56	0.63	0.61	0.72	0.72	0.70	0.71	0.81	0.88	0.73	0.81	0.69	0.81	0.62	0.71
	LH					0.78	0.80	0.95	0.84	1.10	1.01	0.76	0.96	0.65	0.58	0.59	0.61
	HL					.	0.47	0.60	0.54	0.46	0.57	0.52	0.52	0.67	0.60	.	0.64
	HH					0.66	.	0.80	0.73	0.52	0.48	0.64	0.55	0.60	0.65	0.67	0.64

Key: LL = 10 ° C, 12 % mc; HL = 27 ° C, 12 % mc; LH = 10 ° C, 15 % mc; HH = 27 ° C, 15 % mc

APPENDIX F – NEAR INFRARED TRANSMITTANCE

Table F 1: Raw data of % protein content for all 6 hybrids at 4 storage conditions over 18 months

		Dec 00				*Jun 01*				*Dec 01*				*Jun 02*			
Hybrid		***Rep 1***	***Rep 2***	***Rep 3***	***Mean***	***Rep 1***	***Rep 2***	***Rep 3***	***Mean***	***Rep 1***	***Rep 2***	***Rep 3***	***Mean***	***Rep 1***	***Rep 2***	***Rep 3***	***Mean***
Control	***LL***	8.10	8.14	8.11	8.12	8.30	7.90	8.20	8.13	7.50	7.70	8.00	7.73	7.80	7.60	7.70	7.70
	LH					8.30	8.00	8.10	8.13	8.00	7.70	7.30	7.67	8.00	7.60	7.70	7.77
	HL					8.10	8.40	7.90	8.13	7.10	7.70	7.80	7.53	7.80	7.80	7.70	7.77
	HH					8.60	7.90	7.60	8.03	7.90	8.10	7.50	7.83	7.80	7.60	7.60	7.67
Oil treated	***LL***	8.13	8.11	8.16	8.13	8.30	8.40	8.60	8.43	7.90	7.90	7.80	7.87	7.70	7.80	7.70	7.73
	LH					8.10	8.20	7.90	8.07	7.60	7.60	7.60	7.60	7.50	7.50	7.70	7.57
	HL					8.30	8.40	8.50	8.40	7.60	7.80	7.60	7.67	7.80	7.90	7.70	7.80
	HH					8.30	8.40	8.70	8.47	7.70	7.50	7.60	7.60	7.60	7.60	7.80	7.67
High amylose	***LL***	9.67	9.72	9.62	9.67	9.50	9.80	9.40	9.57	9.30	9.80	9.20	9.43	9.60	9.60	9.30	9.50
	LH					9.50	9.40	9.70	9.53	9.40	9.50	9.50	9.47	9.30	9.20	9.40	9.30
	HL					9.90	9.60	9.80	9.77	7.50	7.50	7.40	7.47	9.70	9.70	9.40	9.60
	HH					9.50	9.20	8.50	9.07	8.40	8.90	9.50	8.93	9.40	9.30	8.70	9.13
High Oil	***LL***	7.80	7.83	7.76	7.80	7.80	7.90	8.00	7.90	7.50	7.50	7.40	7.47	7.50	7.70	7.60	7.60
	LH					7.70	7.90	8.10	7.90	8.10	7.90	7.50	7.83	7.70	7.70	7.70	7.70
	HL					7.90	8.00	7.70	7.87	7.90	7.50	7.50	7.63	7.70	7.70	7.60	7.67
	HH					7.60	8.00	7.90	7.83	7.50	7.60	7.40	7.50	7.60	7.70	7.40	7.57
Food grade	***LL***	8.95	9.14	9.12	9.07	8.80	8.70	8.50	8.67	8.40	8.40	8.20	8.33	8.40	8.50	8.40	8.43
	LH					8.70	8.80	9.00	8.83	8.60	8.50	8.20	8.43	8.40	8.50	8.40	8.43
	HL					8.80	8.50	8.80	8.70	8.50	8.10	8.30	8.30	8.50	8.60	8.40	8.50
	HH					8.70	8.60	8.70	8.67	8.30	8.00	8.40	8.23	8.50	8.20	8.30	8.33
Waxy	***LL***	8.03	8.00	7.90	7.98	8.10	8.30	8.20	8.20	7.40	7.50	7.20	7.37	7.70	7.30	7.40	7.47
	LH					7.90	8.10	8.30	8.10	7.60	7.20	7.40	7.40	7.40	7.50	7.50	7.47
	HL					8.30	8.40	7.90	8.20	7.80	7.10	7.80	7.57	7.50	7.40	7.50	7.47
	HH					7.90	7.80	8.30	8.00	7.30	7.10	7.50	7.30	7.50	7.40	7.40	7.43

Key: *LL = 10 ° C, 12 % mc* *HL = 27 ° C, 12 % mc*
LH = 10 ° C, 15 % mc *HH = 27 ° C, 15 % mc*

APPENDIX F – (cont.)

Table F 2: Raw data of % Oil content for all 6 hybrids at 4 storage conditions over 18 months

Hybrid		Dec 00 Rep 1	Rep 2	Rep 3	Mean	Jun 01 Rep 1	Rep 2	Rep 3	Mean	Dec 01 Rep 1	Rep 2	Rep 3	Mean	Jun 02 Rep 1	Rep 2	Rep 3	Mean
Control	LL	3.18	3.16	3.17	3.17	3.12	3.30	3.20	3.21	3.50	3.50	3.20	3.40	3.00	3.00	3.00	3.00
	LH					3.00	3.30	3.20	3.17	3.20	3.10	3.10	3.13	3.10	3.00	3.00	3.03
	HL					3.40	3.40	3.30	3.37	2.90	3.00	3.70	3.20	3.00	3.00	3.20	3.07
	HH					3.40	3.20	2.90	3.17	3.40	3.30	2.70	3.13	3.10	3.20	2.90	3.07
Oil treated	LL	3.30	3.28	3.29	3.29	3.20	3.30	3.40	3.30	3.50	3.50	3.60	3.53	3.10	3.10	3.10	3.10
	LH					3.30	3.40	3.60	3.43	3.10	3.50	2.80	3.13	3.10	3.00	3.10	3.07
	HL					3.50	3.50	3.40	3.47	3.50	3.30	3.30	3.37	3.30	3.00	3.40	3.23
	HH					3.50	3.10	3.40	3.33	3.20	3.00	3.10	3.10	3.00	3.00	3.00	3.00
High amylose	LL	4.50	4.55	4.49	4.51	4.20	4.30	4.30	4.27	3.90	3.90	4.10	3.97	4.20	4.30	4.10	4.20
	LH					4.20	4.50	4.40	4.37	4.20	4.70	4.00	4.30	4.40	4.30	4.30	4.33
	HL					4.30	4.30	4.40	4.33	4.50	4.20	4.20	4.30	4.30	4.30	4.70	4.43
	HH					3.60	3.60	3.10	3.43	4.10	3.40	3.70	3.73	3.60	3.50	3.20	3.43
High Oil	LL	6.37	6.42	6.41	6.40	6.60	6.50	6.73	6.61	6.50	7.20	7.20	6.97	6.80	6.90	6.80	6.83
	LH					6.50	6.90	6.70	6.70	7.10	7.20	6.30	6.87	6.40	6.40	6.50	6.43
	HL					7.00	6.50	6.30	6.60	6.00	6.50	5.90	6.13	6.70	7.30	6.80	6.93
	HH					6.40	5.20	5.70	5.77	6.40	6.10	5.90	6.13	6.90	6.50	5.50	6.30
Food grade	LL	4.30	4.32	4.35	4.32	4.00	3.80	3.90	3.90	3.90	4.10	3.90	3.97	3.90	4.00	3.90	3.93
	LH					4.00	4.10	4.20	4.10	3.90	4.20	3.80	3.97	4.00	4.00	4.10	4.03
	HL					4.10	4.20	4.10	4.13	4.40	4.20	3.90	4.17	4.10	4.10	4.20	4.13
	HH					4.00	4.00	4.00	4.00	4.10	3.50	3.80	3.80	4.20	4.00	4.00	4.07
Waxy	LL	3.50	3.53	3.55	3.53	3.50	3.60	3.50	3.53	3.10	3.30	3.40	3.27	3.60	3.60	3.70	3.63
	LH					3.60	3.40	3.60	3.53	3.70	3.50	3.50	3.57	3.50	3.50	3.60	3.53
	HL					3.80	3.80	3.70	3.77	4.40	3.60	3.80	3.93	3.50	3.60	3.70	3.60
	HH					3.60	3.90	3.90	3.80	3.70	3.70	3.70	3.70	3.60	3.70	3.40	3.57

Key: LL = 10 ° C, 12 % mc; HL = 27 ° C, 12 % mc; LH = 10 ° C, 15 % mc; HH = 27 ° C, 15 % mc

APPENDIX F (cont.)

Table F 3: Raw data of % starch content for all 6 hybrids at 4 storage conditions over 18 months

		Dec 00				Jun 01				Dec 01				Jun 02			
Hybrid		Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
Control	LL	61.6	61.3	61.9	61.6	62.1	61.8	62.2	62.0	60.9	61.0	61.1	61.0	61.2	61.4	61.4	61.3
	LH					61.2	61.4	61.1	61.2	61.1	61.2	61.5	61.3	61.0	61.2	61.0	61.1
	HL					62.0	62.2	62.2	62.1	62.2	61.6	60.4	61.4	61.2	61.0	61.1	61.1
	HH					61.4	60.9	61.1	61.1	61.0	60.6	62.0	61.2	61.1	61.8	61.8	61.6
Oil treated	LL	61.1	61.1	59.9	60.7	61.6	61.8	61.5	61.6	61.0	60.9	61.2	61.0	61.4	61.2	61.3	61.3
	LH					61.2	61.1	61.5	61.3	61.6	60.7	61.6	61.3	61.1	61.3	61.1	61.2
	HL					61.4	61.4	61.7	61.5	60.9	61.4	61.0	61.1	61.0	61.1	60.9	61.0
	HH					60.8	61.6	61.5	61.3	61.1	61.6	61.3	61.3	61.1	61.3	61.1	61.2
High amylose	LL	58.6	57.9	58.3	58.3	59.5	59.8	59.6	59.6	59.6	58.9	59.2	59.2	58.7	58.4	59.0	58.7
	LH					59.0	58.9	59.2	59.0	58.3	57.9	58.6	58.3	58.5	58.8	58.4	58.6
	HL					59.4	59.7	59.2	59.4	57.8	57.2	57.0	57.3	58.2	58.2	57.5	58.0
	HH					59.5	60.3	60.3	60.0	59.8	60.1	58.9	59.6	59.2	59.2	60.3	59.6
High Oil	LL	58.1	58.2	57.9	58.1	58.2	58.8	58.0	58.3	57.8	57.2	57.0	57.3	57.4	57.0	57.4	57.3
	LH					57.8	57.7	58.3	57.9	56.4	56.5	58.7	57.2	57.5	57.6	57.4	57.5
	HL					57.8	58.7	58.9	58.5	57.9	58.1	58.6	58.2	57.3	56.4	57.0	56.9
	HH					57.8	58.8	58.3	58.3	60.9	61.0	61.1	61.0	57.1	57.4	58.3	57.6
Food grade	LL	60.4	60.5	59.9	60.3	61.1	61.1	61.2	61.1	60.4	60.2	60.8	60.5	60.5	60.5	60.6	60.5
	LH					60.6	60.7	60.7	60.7	60.0	59.9	60.7	60.2	60.3	60.2	60.2	60.2
	HL					61.3	60.7	61.1	61.0	59.6	60.7	60.9	60.4	60.1	60.1	59.9	60.0
	HH					60.6	61.1	61.0	60.9	60.4	61.4	60.8	60.9	60.2	60.5	60.4	60.4
Waxy	LL	61.6	61.6	61.4	61.5	61.7	62.1	62.6	62.1	61.5	61.5	61.7	61.6	60.7	60.6	60.6	60.6
	LH					61.1	61.5	60.8	61.1	60.4	60.9	60.7	60.7	60.6	60.7	60.5	60.6
	HL					61.9	62.4	62.4	62.2	57.8	61.4	61.1	60.1	60.8	60.7	60.6	60.7
	HH					61.5	61.2	61.3	61.3	61.4	61.0	60.9	61.1	60.7	60.7	61.0	60.8

Key: LL = 10 °C, 12 % mc; LH = 10 °C, 15 % mc; HL = 27 °C, 12 % mc; HH = 27 °C, 15 % mc

APPENDIX F (cont.)

Table F 4: Raw data of grain density for all 6 hybrids at 4 storage conditions over 18 months

		Dec 00				Jun 01				Dec 01				Jun 02			
Hybrid		Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
Control	LL	1.217	1.214	1.218	1.216	1.235	1.212	1.213	1.220	1.181	1.230	1.243	1.218	1.213	1.218	1.219	1.217
	LH					1.212	1.225	1.215	1.217	1.245	1.227	1.220	1.231	1.232	1.215	1.212	1.220
	HL					1.218	1.218	1.229	1.222	1.231	1.214	1.184	1.210	1.224	1.208	1.221	1.218
	HH					1.208	1.196	1.184	1.196	1.184	1.237	1.212	1.211	1.220	1.225	1.203	1.216
Oil treated	LL	1.213	1.215	1.226	1.218	1.223	1.226	1.224	1.224	1.230	1.226	1.261	1.239	1.223	1.223	1.221	1.222
	LH					1.225	1.216	1.213	1.218	1.237	1.200	1.249	1.229	1.212	1.220	1.218	1.217
	HL					1.217	1.216	1.218	1.217	1.209	1.208	1.202	1.206	1.225	1.215	1.230	1.223
	HH					1.212	1.215	1.221	1.216	1.211	1.150	1.208	1.190	1.211	1.220	1.219	1.217
High amylose	LL	1.281	1.281	1.279	1.280	1.284	1.276	1.271	1.277	1.298	1.293	1.290	1.294	1.287	1.281	1.282	1.283
	LH					1.281	1.283	1.285	1.283	1.283	1.279	1.288	1.283	1.281	1.281	1.285	1.282
	HL					1.279	1.275	1.275	1.276	1.235	1.231	1.232	1.233	1.281	1.277	1.294	1.284
	HH					1.269	1.267	1.249	1.262	1.225	1.279	1.258	1.254	1.277	1.264	1.263	1.268
High Oil	LL	1.230	1.220	1.240	1.230	1.230	1.226	1.226	1.227	1.235	1.231	1.232	1.233	1.230	1.236	1.232	1.233
	LH					1.226	1.226	1.228	1.227	1.229	1.228	1.238	1.232	1.226	1.231	1.224	1.227
	HL					1.228	1.227	1.219	1.225	1.205	1.233	1.237	1.225	1.231	1.218	1.238	1.229
	HH					1.224	1.199	1.193	1.205	1.224	1.220	1.232	1.225	1.214	1.224	1.205	1.214
Food grade	LL	1.291	1.283	1.285	1.286	1.293	1.294	1.295	1.294	1.289	1.284	1.301	1.291	1.295	1.299	1.296	1.297
	LH					1.290	1.288	1.293	1.290	1.301	1.286	1.297	1.295	1.296	1.296	1.296	1.296
	HL					1.296	1.293	1.290	1.293	1.281	1.290	1.300	1.290	1.291	1.291	1.288	1.290
	HH					1.284	1.287	1.280	1.284	1.303	1.280	1.293	1.292	1.291	1.296	1.286	1.291
Waxy	LL	1.236	1.234	1.245	1.238	1.233	1.234	1.230	1.232	1.237	1.237	1.227	1.234	1.228	1.223	1.221	1.224
	LH					1.240	1.226	1.229	1.232	1.238	1.231	1.232	1.234	1.233	1.237	1.233	1.234
	HL					1.237	1.233	1.229	1.233	1.170	1.238	1.237	1.215	1.229	1.222	1.232	1.228
	HH					1.226	1.222	1.219	1.222	1.242	1.221	1.222	1.228	1.222	1.230	1.222	1.225

Key: *LL* = 10 °C, 12 % mc; *HL* = 27 °C, 12 % mc; *LH* = 10 °C, 15 % mc; *HH* = 27 °C, 15 % mc